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SITUATION ASSESSMENT IN AIR-COMBAT: A FUZZY-BAYESIAN HYBRID APPROACH

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ABSTRACT: *In modern air combat operations, the mental workload for fighter pilots is extremely high. The pilot has to make fast dynamic decisions under high uncertainty and high time pressure. This is hard to perform in Within Visual Range (WVR) combat operations, but becomes even harder in Beyond Visual Range (BVR) combat operations where the on-board sensors of aircraft become the pilot's eyes and ears. Typically, the data received from multiple on-board and off-board sensors and sources is fused mentally by operators to produce a coherent air surveillance picture portraying tracks of airborne targets and their classification. Then the air surveillance picture is analyzed mentally to determine the behavior of each target with respect to the own ship and other targets in the region and assess the intent or threat that they pose or the impact they may have on the mission (situation assessment). As the number of targets grows or the situation escalates, the volume of available data from these sensors and sources may overload the operators. To assist them in such situations, it is desirable to automate some of the situation and threat assessment process. In this paper, a Fuzzy logic and Bayesian Network (BN) based hybrid technique is used to investigate the possibilities of design and implementation of an expert system named Intelligent System for Situation Assessment in Air-Combat (ISSAAC) as an aid to pilots engaged in air-combat. ISSAAC is a pilot-in-loop (PIL) simulator consisting of integration of platform models, sensor models, pilot mental models and data processing algorithms. The capability of ISSAAC is demonstrated by simulating an air-to-air combat scenario consisting of six targets.*

1. INTRODUCTION

Air combat decision-making is a complex task accomplished by a team of highly skilled personnel. Threat and Situation assessment are fundamental components in that decision-making process. Air combat operators of modern military airborne platforms rely on data from multiple sensors and sources to achieve their missions. Typically, the operators combine the data manually to produce a coherent air surveillance picture portraying tracks of airborne targets and their classification. Then the air surveillance picture is analyzed mentally to determine the behavior of each target with respect to the own ship and other targets in the region and assess the intent or threat that they pose or the impact they may have on the mission. This analysis is commonly referred to as Situation Assessment (SA) [2]. As the number of targets grows or the situation escalates, the potential exists for the volume of available data to overload the operators. It is therefore desirable to assist the operators by automating some of the situation and threat assessment processing.

The crucial problem that decision makers face in air-combat is the problem of uncertainty. Many methods exits in artificial intelligence and expert systems literature which can handle uncertainty quite adequately, viz. fuzzy logic, belief functions, neural networks etc. However, a probabilistic approach has the advantage that it is based on a rigorous theory with a vast amount of known results. This is a great advantage and has in fact caused many to claim that probability is the only sensible description of uncertainty and is adequate for all purposes [6]. But probability requires a vast amount of storage and computational manipulation making probabilistic methods computationally infeasible. To overcome these requirements the Bayesian networks were formulated [7, 8]. The Bayesian approach has many feasible features, but lack the ability to handle continuous input. If integrated with the Fuzzy approach of making the data members of discrete sets, the hybrid system should be able to handle all the demands of the Situation Assessment. This paper uses a Fuzzy-Bayesian hybrid technique to investigate the possibilities of design and implementation of an expert system named Intelligent System for Situation Assessment in Air-Combat (ISSAAC) as an aid to pilots engaged in air-combat. Section 2 describes the ISSAAC simulator, while section 3 provides the details of Bayesian mental model of the pilot. Section 4 presents the results of simulation of an air-to-air combat scenario. Finally section 5 contains some concluding remarks.

2. ISSAAC DESCRIPTION & ARCHITECTURE

ISSAAC is a Pilot-In-the-Loop (PIL) simulator consisting of integration of sensor models (ISM), platform models (Execon), pilot mental models and data processing algorithms. The complete system is implemented in real-time. The architecture of the ISSAAC is illustrated in Figure 1, and consists of five distinct modules: 1) an interactive GUI named Exercise controller (Execon) for air combat scenario generation; 2) the airborne sensor model ISM; 3) Data Processor; 4) Pilot mental model; and 5) Graphical display. Arrows indicate the flow of information between the different modules.

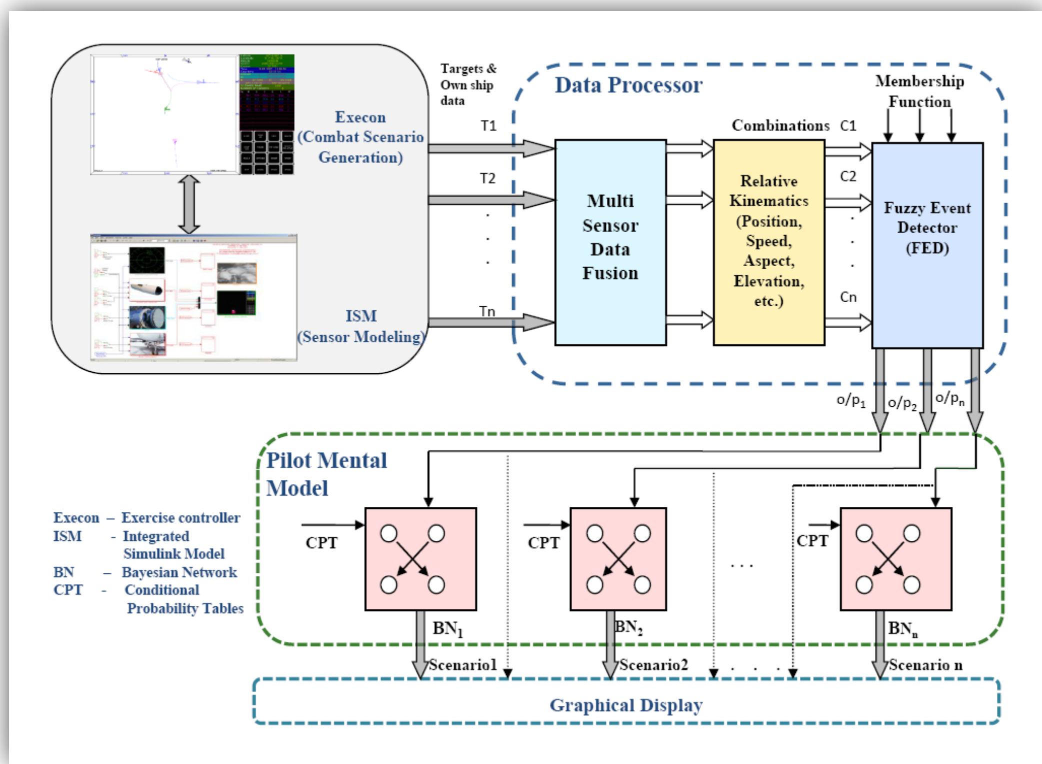

Fig. 1 Architecture of ISSAAC simulator

The **Exercise controller (Execon)** developed in C++ consists of platform models of fighter, Bomber, Missile, Helicopter and Transport Aircraft. Execon can be used to create any typical air-to-air combat scenario consisting of maximum of 6 targets (excluding the own ship). The Exercise controller (Execon) has a simple user interface consisting of a display area, status area and menu area. The display area displays the windows, sub-windows and targets during the simulation. The status area displays important simulation related parameters such as speed, course, bearing, coordinates, and RADAR status. Targets are represented by specified shapes and colors to distinguish which platform types they represent. Class and ID of all targets must be specified prior to the simulation. Each target is either controlled via predefined trajectories or via user interaction in real-time.

The **Integrated Simulink Model (ISM)** developed in MATLAB-SIMULINK consists of functional model of different sensors namely, RADAR (Doppler), Infrared Search and Track (IRST), Radar Warning Receiver (RWR) and Electro-Optical Tracking System (EOTS).

The **Data Processor** module consists of three sub-systems namely, Multi-Sensor Data Fusion, Relative Kinematics and Fuzzy Event Detector. It combines and classifies the data received from the multiple sensors. Extended Kalman Filter (EKF) is used to estimate the states of the targets using fused measurements from multiple sensors [9]. The Fuzzy Event Detector classifies the relative kinematics data into qualitative form (events) e.g. Speed is 'low', 'medium' or 'high'. MATLAB based Fuzzy logic toolbox (FLTB) is used to design appropriate membership functions for data classification.

The **Pilot Mental Model** emulates the pilot's information processing, situation assessment, and decision-making activities, based on information received from the Data Processor. Agents based on Bayesian network technology are developed to assess the occurrence of different situations in air-combat. The **HUGIN C++ API** software tool [4] is used for the construction and propagation of Bayesian networks.

The **Graphical Display** provides the updated probabilities of all the agents.

3. BAYESIAN MENTAL MODEL

A mental model of Situation Assessment requires a technology which has: 1) the capability to quantitatively represent the key SA concepts such as situations, events, and the pilot's mental model; 2) a mechanism to reflect both diagnostic and inferential reasoning; and 3) an ability to deal with various levels and types of uncertainties. Bayesian network (BN) technology is an ideal tool for meeting these requirements and modeling SA behavior. Bayesian networks (also called Belief networks, inference nets, or causal nets) are directed acyclic graphs (DAGs) in which nodes represent a probabilistic variable whose probability distribution is denoted as a belief value and the links represent informal or causal dependencies among the variables. The strength of a dependency is represented by conditional probability tables (CPTs) that are attached to each cluster of parent-child nodes in the network [8].

In this paper, three agents based on BN technology are developed to assess the occurrence of different situations in air-combat [5]. The three agents and their tasks are: 1) Pair agent: two or more targets are in formation e.g pair of aircrafts; 2) Along agent: aircraft flying along an air-lane; 3) Attack agent: one target attacking another target, e.g fighter attacking the own ship. Development of each agent consists of two steps; 1) a BN structure to represent the pilot mental model and 2) a belief update algorithm to reflect the propagation.

3.1. Pair Agent Bayesian Network Model

Figure 2 shows the proposed Pair agent Bayesian network model to compute the updated probabilities. Distance, ID, Class, Course, Elevation and speed are the independent nodes or Information nodes. It is assumed that the inputs 'Distance', 'Course', 'Elevation' and 'Speed' have three states: Small, Medium and Large. The input 'ID' has three states: Friend, Unknown and Foe. The input 'Class' has four states: Fighter, Bomber, Transport and Missile. The Intermediate node 'Kinematics' has two states: Same and Different. Finally the Pair node is the Hypothesis node and it has two states: Yes and No. The semantic rules of Pair agent are:

- If two aircraft have the same Course, Elevation and Speed, then they have the same Kinematics.
- If two aircraft have the same Kinematics, the same Identity, the same Class, and are at a short Distance from each other, then they form a pair.

3.2. Along Agent Bayesian Network Model

Figure 3 shows the proposed Along agent Bayesian Network model to compute the relationship between the air-lane and the aircrafts. Class, Distance and Course are the Along agent input nodes. The inputs nodes 'Distance' and 'Course' have three states: Small, Medium and Large. The input 'Class' has four states: Fighter, Bomber, Transport and Missile. The Along node is the Hypothesis node and it has two states: Yes and No. The semantic rules of Along agent are:

- If an aircraft has the same Course as an air-lane, and if it is Close to the air-lane, then the aircraft is flying Along the air-lane.
- If an aircraft is transport there is a higher possibility that the aircraft is flying Along the air-lane.

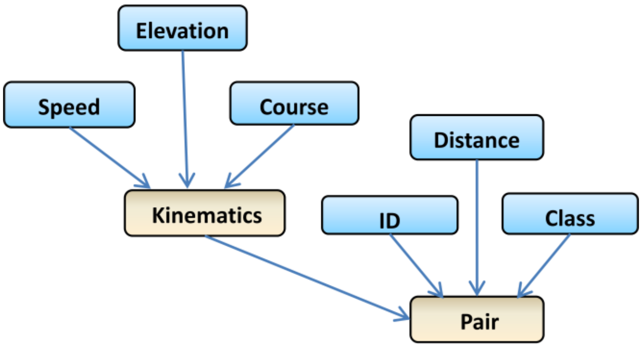

Fig. 2 Pair agent Bayesian network model

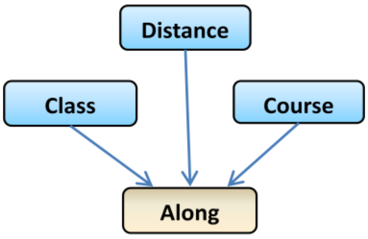

Fig. 3 Along agent Bayesian network model

3.3. Attack Agent Bayesian Network Model

Figure 4 shows the proposed Attack agent Bayesian network model to compute the attacking probabilities. The ID, Class, Distance, Aspect and Speed nodes are the input nodes. The states of input nodes 'ID', 'Class', 'Distance', and 'Speed' are same as given in Pair agent. The 'Aspect' node has three states: Small, Medium and High. The Intermediate node of the attack agent is the Closing node. It has two states: Yes and No. Finally Attack node is the Hypothesis node. It has two states: Yes and No. The semantic rules of Attack agent are given below:

- If an aircraft has high Speed, has a close Distance to another aircraft and has a heading towards (high Aspect) it, then the aircraft is trying to Close in on the other..
- If an aircraft is Closing in on another, and has a different ID and is a fighter aircraft, then the aircraft is Attacking the other.

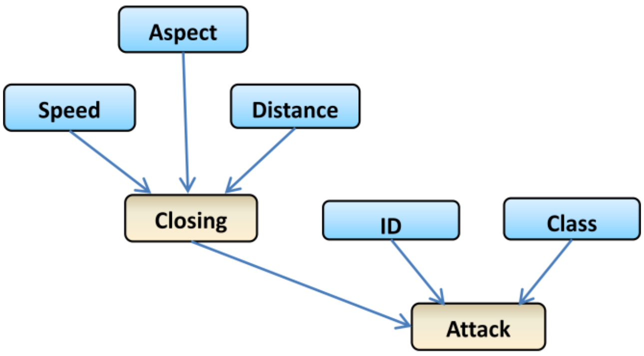

Fig. 4 Attack agent Bayesian network model

Table 1 Scenario information

TARGET NO	CLASS	ID
1	Fighter	Foe
2	Fighter	Foe
3	Fighter	Friend
4	Fighter	Unknown
5	Missile	Foe
6	Transport	Friend

4. SIMULATION RESULTS

The demonstration scenario shown in Figure 5 consists of six targets, five of which are aircraft, and one is a missile. The scenario information is provided in Table 1. Figure 6 shows Attack agent probabilities. The attack agents detected 4 active relations between own ship and the targets 1(foe), 2(foe), 4(unknown) & 5(foe). Target 5 has the highest probability as expected (because it is a missile and close in on from behind). Targets 3 & 6 have lowest probability (both are friends). Figure 7 displays Pair agent probabilities. The Pair agent detected a pair between targets 1 & 2 which lasted until 20 seconds. Pair agent did not detect a pair between targets 3 & 4 because their IDs are different (see Table 1). Along agent probabilities are displayed in Figure 8. The along agent found the relationship between target 6 and the air lane. The air lane is a virtual object, and was inserted in a database before the simulation.

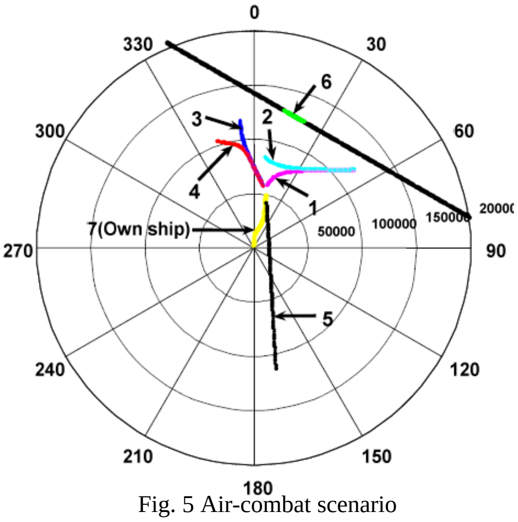

Fig. 5 Air-combat scenario

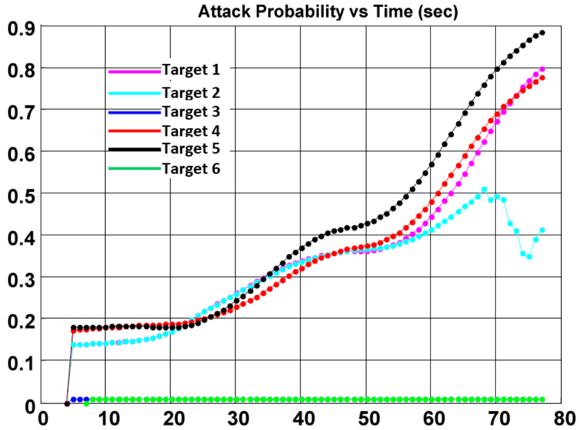

Fig. 6 Attack probabilities

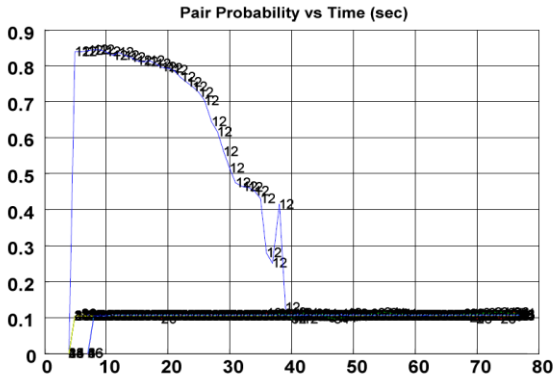

Fig. 7 Pair probabilities

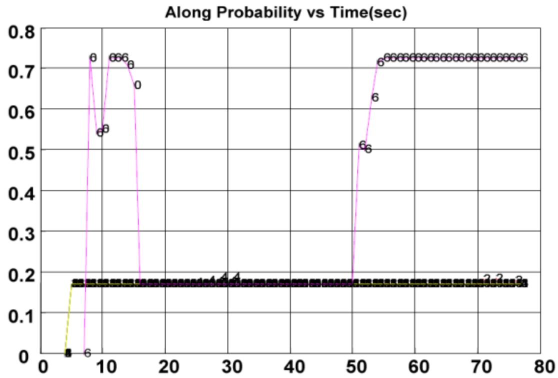

Fig. 8 Along probabilities

5. CONCLUDING REMARKS

ISSAAC is implemented using Fuzzy logic and Bayesian network hybrid technique to find out the exact situation in an air-to-air combat scenario, which helps the pilot to take correct and quick decision. The capability of ISSAAC has been demonstrated by simulating a typical air-to-air combat scenario. It is observed that the BNs based on several agents were able to accomplish the job assigned with fairly good amount of precision. However, further improvement of ISSAAC performance is envisaged by fine-tuning of entries of CPTs corresponding to different agents with the help of experienced pilots for typical combat scenarios. Ongoing effort on performance metrics is being conducted to further enhance the SA process.

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